INLAND SEAS ENGINEERING
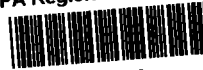
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December 12, 2005

Ms. Sy Paulik, EQA
Michigan Department of Environmental Quality
120 West Chapin Street
Cadillac, Michigan 49601

Re: Pond Release Response Plan
    Cherry Blossom LLC
    ISE Project No. 02061-59E

Dear Ms. Paulik:

On November 8, 2005 a release of impounded wastewater occurred from the storage pond at Cherry Blossom, LLC. The release reportedly occurred before dawn on November 8th as a result of a failure of the west wall of the earthen berm which serves to impound the wastewater. Inland Seas Engineering, Inc. (ISE) conducted an initial assessment of the areas affected by the release on November 22nd and 23rd.

The intent of the preliminary assessment was to gather information regarding fate of the wastewater released, the initial abatement activities conducted in response to the release and to make an initial assessment of areas affected in support of further response activities. On November 29, 2005 ISE submitted a report to the Michigan Department of Environmental Quality (MDEQ) which summarized the initial findings from the preliminary assessment.

Through this initial assessment and supplemental assessments undertaken at the site on December 2nd and 5th, four (4) geographic areas have been identified as requiring further assessment or response activities. These areas are hereinafter referred to as:

- Proximal on-site accumulation area (Area A)
- Distal on-site accumulation area (Area B)
- Munro Road drainage ditch and (Area C)
- Off-site accumulation area (Area D)

These geographic area are depicted on Figure 1 in relation to other regional geographic and cultural features. They are also shown in greater detail on Figure 2 and Figure 3.

INTRODUCTION

In order to determine potential impact of the release throughout the above-referenced areas, chlorides were selected as a screening parameter as it is non-reactive and present in measurable concentrations in pond water. During the initial phase of the investigation, chloride concentrations were analyzed in water samples from the release area and from areas of accumulation, and in soil samples from areas that were known to have accumulated pond water from the release. Areas that exhibited a potential risk of negative impact based on initial screening efforts were selected for further evaluation.

Assessment activities are intended to support response and further spill abatement activities that are necessary to mitigate unacceptable exposure risks to hazardous substances dissolved in the released pond water. Route of potential exposure and sensitive receptors considered include:

> Off-site flora (phytotoxicity effects)
> Drinking water ingestion- humans (aesthetic considerations)

Potential adverse exposure may arise through transport of hazardous substances contained in soils (pooled areas) through:

- leaching (through infiltrating precipitation) to the water table and migration to potable water wells
- saturated vertical flow to the water table and migration to potable water wells

In addition, phytotoxic effects to flora may arise if adversely sodic conditions develop within the root zone in areas where the released pond water accumulated and infiltrated.

The fate and transport of chlorides was evaluated in the assessed areas of contamination. Potential contamination from a release area occurs by transporting contaminants from pooled areas of release to the soils, and eventually to the water table. The rate of chloride transport from these discrete pooling areas to soils and groundwater depends upon the concentration of the chloride within the released pond water, texture, porosity and hydraulic conductivity of the soils in the release area, infiltration of precipitation into the assessed area, and degree of saturation of the soils.

Movement of water through the soil can be estimated for saturated and unsaturated soil using equations based on Darcy's law. The U.S. EPA Superfund Exposure Assessment Model (EPA/540/1-88/001, OSWER Directive 9285.5-1, April, 1988) provides the following equations for estimating vertical flow through the vadose zone, which can be used to estimate the time for contaminants to transport through the soil to groundwater.

The percolation rate can be estimated using the following equation from the same source:

> <u>Equation 1: Percolation rate</u> q (depth per unit time) $= HL + P_r - ET - Q_r$
> where HL = Hydraulic loading from manmade sources, (depth per unit time)
> > P_r = Precipitation, (depth per unit time)
> > ET = Evapotranspiration, (depth per unit time)
> > Q_r = Runoff, (depth per unit time)

Assuming Q_r and HL to be zero (0), contaminant loading rates can be calculated for the areas of pooled pond water.

Vertical flow can be estimated using equation 2.

Equation 2: Interstitial pore velocity: v_{pw} (depth per unit time) $= q/\Theta$
where v_{pw} = Interstitial ground water (pore water) velocity, (lenth per unit time)
q = average percolation or recharge rates (see above)
Θ = volumetric moisture content of the unsaturated zone, (decimal fraction representing volume of water per volume of soil)

The four (4) areas of assessment were evaluated for chloride concentration within surface soils, pooled release areas, and, where appropriate, within the shallow groundwater table. Soil observations and moistures were also obtained in the assessment areas. Transport of chloride to soil and groundwater were evaluated in the individual areas based on observations, analytical results, and estimates of chloride transport through the soils. Results indicate the following:

- Chloride concentrations in Area A exceed direct contact criteria.
- Chloride concentrations within the retention basin areas within area B are lower than concentrations in the pond area
- Chloride concentrations at one soil boring within the drainage ditch (Area C) exceed direct contact criteria.
- Area D indicates specific zones that exceed direct contact criteria.

The specific area assessments, near term response activity plans, and future response activity plans follow in this letter report.

METHODS AND RESULTS

Proximal On-Site Accumulation Area (Area A)
Chloride concentrations measured in the pond indicated a concentration of 865 PPM. Although a pond level was not immediately obtained after the release, the point of failure was at the west side of the pond.

Three (3) soil borings were advanced within Area A, which is denoted as the lower pooling area (A1). Soil borings are presented in Figure 2 (SB-110 – 112). Soil observations noted by ISE denoted medium grained sand with varying amounts of clay, it was brown to black in color and moist in the first foot below the ground surface. The black color was associated with plant materials. Soils in the four (4) to five (5) foot range were described as medium-grained, light brown, moist sand with traces of clay and silt.

Soil samples from area A1 were submitted to SOS Analytical Laboratories for analysis of chlorides. Analytical results reported chloride concentrations ranging from 214 to 2,020 mg/kg (PPM) in the surface samples within the zero (0) to one (1) foot below ground level (bgl) range and were at 19 PPM within the four (4) to five (5) foot bgl range (see Table 1). Two depths were analyzed for SB-111. The reported chloride concentration at SB-111 between zero (0) to one (1)

foot was 314 mg/kg, while the chloride concentration at the four (4) to five (5) foot level was 19 mg/kg.

The soil moistures indicate that at the time of sampling there was significant available water capacity within the soil, in other words, soils were not saturated or even near saturation. Analytical results for soil moisture at the four (4) to five (5) foot level indicated 10.5 percent moisture as opposed to 4.1 percent within the first foot. Soil moisture is higher in the four (4) to five (5) foot level. Soil moisture levels throughout this interval assessed indicate that additional field capacity remains and vertical saturated flow is not likely to occur. Further vertical transport through leaching will be impeded by tensile capillary forces in the unsaturated zone.

On December 2 Area A was reassessed, and the area of impact was expanded to include an additional area of pooling (upper pooling area A2). Area A2 , shown in Figure 2, is bordered on the south by a road that divides area A1 and A2. Additional soil borings were advanced within this area of depression located west of the pond.

Surficial soil conditions in area A2 were wet during the sampling event. Five (5) soil borings were advanced, one (1) on the north, south, east and west boundaries of the basin and an additional boring located in the center (SB-114-SB-118). Surficial samples were submitted for chloride analysis to SOS Analytical Laboratories from the upper two feet from all borings.

Results in area A2 indicated that concentrations exceed direct contact criteria (phytotoxicity) for all samples except the soil boring located east of the upper area of pooling (SB-114) and the soil boring located on the eastern edge of the lower pooling area (SB-119). Concentrations were highest at SB-115.

According to the Grand Traverse County Soil Survey, the soils in this area are described as Leelanau-Kalkaska Sandy Loams. Using Equation 1 and Equation 2, an estimate of vertical contaminant transport was calculated. Calculations for Area A, B and C (sandy loam) indicate vertical transport of .07 inches/day (see Table 3).

Distal On-Site Accumulation Area (Area B)
Prior to repairing the pond, the release followed the topography at the site, flowing in a southwesterly direction to the retention pond area that is used for collecting storm water runoff from the upper parking lot and storage areas. The pond water path continued south, filling in the southern curve of this retention area, then overflowed to the southwest towards the former brine mixing area. The flow eventually pooled on the asphalt pavement between the maintenance building and cherry processing plant. Some flow proceeded through the storm water structure to the lower retention pond north of the maintenance building.

According to Mr. Hubbel, prior to the release there was some stormwater contained in the retention areas. During initial response efforts, some water was pumped from the retention area behind the maintenance building back into the storage pond in an effort to provide capacity for the accumulation south of the maintenance building.

Some water that accumulated in the upper parking lot retention pond area leaked through a twelve-inch drain tile previously blocked with soil. The release was directed through a drain pipe in the ditch to flow downhill to the County right-of-way and the Munro Road drainage ditch.

Water samples were obtained from the retention areas for analysis of chlorides. The concentrations of chlorides were approximately 15 percent of the pond water concentration in the upper retention area and approximately 25 percent of the pond water concentration in the lower retention area (see Table 1). Soil borings were not advanced within Area B as pond water accumulation areas that had been pumped back to the pond subsequently contained storm water from recent precipitation.

Drainage Ditch (Area C)
On November 22 and 23 a soil boring (SB-113) was advanced in the drainage ditch to determine depth to groundwater and to obtain a water sample. On December 5, 2005, ISE attempted to set a temporary monitoring well (SB-130) in the drainage ditch. Groundwater was not encountered within thirteen feet of the advanced soil boring. The ground elevation of SB-130 is approximately 622.5 feet above sea level (Figure 1).

Soils observed were described by ISE staff as sand with trace silt, trace gravel to seven (7) feet bgl. A clay with some sand, trace gravel was encountered from 7.5 – 8.5 feet. The top of this layer was moist to wet but would not produce sufficient water for sampling in either SB-113 or SB-130. Alternating moist layers of sand with little clay, and silt with some clay were encountered from 8.5-11 feet. The boring was advanced to 2 feet into a clay with some sand and gravel, where the boring was terminated. A soil sample collected at 3 feet below grade was submitted to SOS Analytical Laboratories for analysis of chlorides. Laboratory analytical results of chloride indicate 584 mg/kg for SB-130.

Off-Site Accumulation Area (Area D)
Reported analytical results indicate chloride concentrations exceed the direct contact (plant-phytoxicity) criteria for chlorides in SB-101 and SB-108. Additional soil samples were obtained on December 2 and December 5 to further delineate chloride concentrations within Area C. Sixteen soil samples have been submitted from this area. Based on the results, there are three (3) areas that contain chloride concentrations that exceed the direct contact criteria. These areas are presented in Figure 3.

The culvert that discharges to Area D (Figure 3) collects stormwater runoff that collects from Angell and Munro Road. Recognizing potential for accumulated salt contamination from road runoff in this area exists, background soil samples were taken from areas located on the north side of Angell Road in an area that would not have been impacted by the pond water release that traveled through the culvert underneath Angell Road (SB-128) and also from the south side of Angell Road, east of the culvert discharge. In addition, a soil sample was obtained from the intersection of Elk Lake and Angell Roads, which is located east of the Munro and Angell Road intersection (SB-129). Results for these background samples, SB-127 and SB-128, indicate chloride concentrations of 115 and 40 PPM, respectively.

In addition to the soil samples obtained on December 2, two (2) surface water samples were submitted for analysis of chlorides from Area D. Results indicate that chloride concentrations were at 28 and 36 mg/L (PPM) for the samples.

Temporary monitoring wells (TMW-1 and TMW-2) were installed on December 5, 2005. Water was encountered at two (2) feet bgl. Samples were screened from zero (0) to 3.7 feet bgl at TMW-1 and zero (0) to five (5) feet bgl at TMW-2. Samples were collected with a peristaltic pump and submitted to SOS Analytical Laboratory for analysis of chlorides on December 6, 2005. Reported analytical results showed chloride concentrations at 184 and 52 PPM for TMW-1 and TMW-2, respectively.

R. Brown and Associates were utilized by Cherry Blossom LLC to delineate wetlands within Area D. They visited the site on December 2, 2005, and determined that the area is a wetland and would require permitting if excavation is to be conducted. A Category "M" General Permit was submitted to MDEQ one December 6, 2005. According to Bruce Jones of R. Brown and Associates, Eric Hudy, MDEQ, stated that the permit will receive priority so that excavation in the wetland area can proceed.

CONCLUSIONS (PRELIMINARY)

Lower pooling area (A1)
The concentration data demonstrate that chlorides appear to be held in the available pore space in the upper foot within the transect located in the lower pooling area in Area A. Soil concentrations also indicate that the chloride concentrations were below established residential criteria for chlorides within this zone, with the exception of SB-110, which exceeded direct contact criteria.

The release occurred on November 8, 2005. The calculated vertical contaminant transport estimated vertical movement of contaminants at a rate of .07 inches/day. As of today's date, the calculation predicts contamination would have moved very little vertically beyond the initial depth of infiltration. Soils within the lower pooled region within the four (4) to five (5) foot range show a decrease in chloride concentrations, indicating that the estimate may reliably predict vertical transport rates.

Upper pooling area (A2)
Direct contact criteria is exceeded in all samples taken within area A2, except for the most eastern sample (SB-114). Samples beyond two (2) feet have not been obtained in area A2, therefore, a conclusion regarding initial infiltration below the upper two (2) feet of soil cannot be made.

Area B
The upper and lower storm water retention basin areas have relatively lower chloride concentrations, likely due to the fact that storm water was present in the pond areas at the time of

the release. Protection from rainwater infiltration (covering) at the retention ponds is not deemed necessary due to this reduced concentration.

Soil sampling has not been conducted beneath the ponds or at the area of the breach on the west side of the upper retention area that caused the release to the drainage ditch. If the chloride contaminant transport model is assumed to be accurate, and estimated groundwater to be at approximately 33 feet bgl based on topographical observations, it would take approximately 500 days to reach the groundwater table.

Area C
Groundwater was not encountered within the upper 13 feet of the vadose zone soils.. The soil boring indicated chloride concentrations exceed direct contact criteria at three (3) feet bgl. The extent of soil contamination, both laterally and vertically, has not been fully ascertained.

Area D
Based on chloride analytical results, there are three (3) areas that exceed direct contact criteria for chlorides. Two (2) shallow wells indicate chloride concentrations have not exceeded drinking water criterion.

NEAR TERM RESPONSE MEASURES
Chloride concentrations indicate that there is a certain extent of chloride contamination in the areas where pooling occurred in area A. The contamination does not appear to be migrating towards groundwater according to results in area A1, however, continued infiltration could cause a downward migration (leaching) of soil chloride. Measures to prevent future infiltration include removal of snow cover and placement of a protective liner over the soils in areas A1 and A2. In addition, soil borings should be advanced to at least five (5) feet in the central portion of the upper pooling region of Area A. Placing a liner over the soils would prevent infiltration and continued vertical leaching of chloride ions.

Sampling of the soil in the area of the breach and other locations in the retention pond vicinities in Area B should be conducted. This sampling should occur at various depths to ascertain the vertical distribution of chloride. This should be compared to vertical migration model calculations.

Although the shallow water table was not reached during the investigation, a soil sample was obtained from the drainage ditch (Area C). Since analytical results indicate elevated levels of chlorides in the soil, a temporary well will be set and a shallow water sample will be obtained. Additional soil samples will be obtained along the ditch. In addition, soil samples will be obtained to ascertain impact of road salt on surface soils. Acquisition of a right-of-way permit for this assessment work is underway.

Excavation will occur within Area D when an approved wetlands permit has been received from MDEQ, and when a NREPA Part 91 permit is obtained from the County. A right-of-way permit has been obtained from the county and a Part 91 Permit application has been submitted with a request for expedited review.

When all chloride analytical results have been obtained a map will be constructed to indicate soil chloride concentrations. Areas that are above the direct contact criteria for chlorides will be excavated to a depth of approximately two (2) feet, just above the water table. Soil samples will be obtained during the excavation to ensure that "clean" soils remain. Prior to excavation, benchmark and spot elevations will be obtained to enable reestablishment of grade within the wetland area.

Excavated soils will be stockpiled on site beneath a protective PVC cover to allow an investigation of alternatives for use and/or disposal. The disturbed area will be filled with sand and a six-inch layer of topsoil at the surface. Re-vegetation will occur next spring in accordance with the pending wetland permit conditions. Shallow groundwater monitoring will be conducted adjacent to Area D, between this area and Tobeco Creek to monitor the effectiveness of excavation efforts.

FUTURE RESPONSE MEASURES
Future response measures are evolving as data from on-going assessment activities yield further insight into the nature and extent of the pond water release. This may require modification of and addition to near-term response measures. Areas B requires additional investigation and Area C may also require characterization beyond the near-term measures identified above, dependent upon soil and groundwater results from initial characterization efforts.
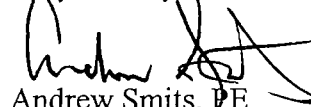
All affected areas are to be addressed in a Remedial Investigation Work Plan (RIWP) required by MDEQ to address all known release areas and to evaluate the fate, transport and potential receptors of hazardous substances released at the site. The RIWP will also include plans for long-term monitoring of groundwater.

If you have any questions regarding the investigation of the release, please call me at (231) 933-4041.

Prepared by:
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INLAND SEAS ENGINEERING, INC.

Exemption 6, 9 applies

Attachment 1: Excerpts from EPA/540/1-88/001

⚬EPA

Superfund Exposure
Assessment Manual

EPA   FINAL GUIDELINES FOR EXPOSURE ASSESSMENT
FR, Vol. 57, No. 104, FRIDAY MAY 29, 1992 pp 27SER-27938

data for the top cm of soil only. This value is then used in Equations 2-27 and 2-28 to estimate runoff losses on a single storm event basis.

Research based on the work of Haith et al. (1980) is currently underway at Cornell University* to develop runoff loading factors for organic chemicals in soils. After these factors are devised, the analyst will be able to obtain average loading values based solely on a chemical's octanol/water partition coefficient and the geographic location under study. This will greatly simplify the generation of long-term average release estimates.

Note that in order to estimate long-term and short-term contaminant concentrations in surface water, the long-term and short-term release values are used, along with average and minimum streamflow data as described in Chapter 3, Environmental Fate Analysis.

2.5 Quantitative Analysis of Ground-Water Contamination

Surface soils at uncontrolled hazardous waste sites may become contaminated with toxic materials as a result of (1) the intentional placement of wastes on the ground (dumping, landfarming), (2) spills, (3) lagoon failure (overland flow), or (4) contaminated site runoff. Leaching of toxics from a contaminated soil surface can carry contaminants into subsurface layers.

2.5.1 Beginning Quantitative Analysis

2.5.1.1 Leachate Release Rate
This section presents simplified approaches for estimating contaminant release rates to ground water. Such estimation can be determined for dry landfills, lagoons, or wet landfills, whether unlined or lined with clay or flexible membrane liners.

(1) Estimating Release Rate from Facilities Lined with Clay or Natural Soil
Release rate estimation involves the determination of both the contaminant concentration in the leachate and the volumetric flux of leachate. The determination of contaminant concentration is made using equilibrium conditions (steady state), whereas the volumetric flux can be ascertained with instantaneous time-varying models or with steady state equations.

Modeling the release rate of toxic constituents can thus be done in terms of either the instantaneous time-varying releases or the annual average release (i.e., steady state release rate based on an annual average). This section discusses the determination of the steady state release rate (annual average); the

equations are simpler than the computer models necessary for instantaneous time-varying releases. Analysts interested in performing instantaneous time-varying release rate determinations are referred to Chapter 3, where the HELP and SESOIL models are discussed. HELP and SESOIL are appropriate for modeling dry solid waste in a landfill or landfarm situation; they are not appropriate for modeling the release rate of liquids from lagoons, landfills, or landfarms. Rainstorms come in discrete intervals separated by dry periods. Using steady state equations to model rainfall-induced leaching, however, assumes that 1/365th of the annual recharge occurs each day. Although this is an assumption, it is felt to be a useful one for most cases. Most abandoned hazardous waste sites have received liquids in the past; very few have received only dry solids. Hence, the question of the assumption of steady state conditions is relatively moot. For the bulk of the modeling situations (liquid wastes), the steady state and the instantaneous rates are the same, and since the steady state equations are simpler, they are the method of choice.

For lagoons, the analyst should use the concentration of contaminant in the lagoon as the concentration of the contaminant leaving the lagoon, since the "leachate" is the waste itself. The waste leaves the lagoon by percolating through the clay liner or the native soil, or it permeates the flexible membrane liner (FML).

For landfills, the analyst should use the equilibrium solubility of the solid waste, assuming that the contaminant will have fully equilibrated with the percolating rainwater. The use of the equilibrium solubility concentration as the leachate concentration is an assumption, it is based on a typical residence time of 21 years for rain percolating through a covered (10^{-7} cm/sec) secure landfill. The assumption is that the time used for determining the equilibrium solubility of the chemical is much shorter than the residence time in the fill. If the fill is uncovered (or covered with a permeable cover), the travel time through the landfill may be too short for the above assumptions to be valid. In these cases, the analyst should calculate the travel time and compare it to the time used in the solubility test. If the travel time is not longer than the test time, the analyst should estimate the leachate concentration as a fraction of the equilibrium solubility concentration. Additionally, the above assumptions assume a landfill of only one waste stream, if the fill has only a small quantity of the subject waste in it, the contact time is the time for travel through the isolated material. In these conditions, the leachate concentration will typically be a fraction of the equilibrium solubility. The analyst may wish, in some instances, to model the solubility of the contaminant within a complex leachate. In this case, the solubility of a hydrophobic

contaminant can be increased by the organic fraction of the complex leachate.

For landfarms, the assumption that adequate residence time is available for contaminants to reach equilibrium solubility may not be viable, and the analyst should estimate the degree of solubilization. This can be done by dynamic modeling of the kinetics of dissolution, or it can be approximated based on experience and engineering judgment. Because of the complexities of dynamic modeling, this approach usually is not worth the slightly increased accuracy gained, especially since other parameters may affect the accuracy of the final answer. Concentration is typically estimated as a fraction of the equilibrium solubility.

The volumetric flux of contaminated water can be calculated in two ways, one for solid wastes and one for liquid wastes.

(a) For landfilled solids, the only liquid present is water percolating into the fill. For uncovered landfills, this can range from the infiltration fraction of the rainfall, to the full precipitation (if no rain runs off of the fill before infiltrating), to larger flows of water if the site is exposed to stormwater run-on from an adjacent area. For covered landfills, the infiltration fraction may be limited by the permeability of the cover. Typically in wet climates the cover permeability is limiting, while in dry climates the permeability does not limit percolation, and normal soil percolation ratios can be used.

The loading rate to ground water can be calculated with the following equation:

$$L_c = q * A * C_0 \qquad (2\text{-}32)$$

where

L_c = contaminant loading rate, (mass/time).
q = percolation rate, see Equation 3-14 for calculation of q, (length/time).
A = area of landfill, (length squared).
C_0 = solubility of solid chemical, (mass/volume).

(b) For lagooned or landfilled liquids, precipitation has a minimal influence on leachate generation, as liquid waste will percolate to the watertable under the influence of gravity. The rate-determining step is the permeability of the liner or underlying soil (if there is no liner). For liquids, the following form of Darcy's law should be used to estimate the volumetric flux leaving the site.

$$Q_l = K_s * i * A \qquad (2\text{-}33)$$

where

Q_l = volume loading rate, (volume/time).
K_s = Darcy's coefficient; for unlined lagoons use native soil hydraulic conductivity; conductivity (length/time) (see Chapter 3 for sources of hydraulic conductivity).
i = hydraulic gradient, (length/length). Equations 2-33 will handle situations where the liquids in the lagoon have a free depth. In many cases the depth of the free liquids is small, or it is small with respect to the distance between the lagoon and the watertable (when the Ks is for native soil). In these cases the term "i" can be taken as 1.
A = area of lagoon, (length squared).

This Q_l is then used to estimate mass loadings with the following equation:

$$L_c = C_s * Q_l \qquad (2\text{-}34)$$

where

L_c = contaminant loading rate, (mass/time).
C_s = contaminant concentration in lagoon fluid, (mass/volume).
Q_l = volume loading rate, (volume/time).

Equations 2-33 and 2-34 model the release rate from a lagoon whether the flow through the vadose zone is saturated or unsaturated. For unlined active lagoons, the flow is typically saturated all the way to the watertable. For clay-lined lagoons, the flow is saturated through the liner and unsaturated between the liner and the watertable (assuming no breaches in the liner). Equations 2-33 and 2-34 are appropriate when analyzing lagoon releases, but should not be used for spills or other conditions where the chemicals on the surface do not pond for a long time. In these conditions, the assumption of saturated flow (through the liner or soil) may be violated.

Equations 2-33 and 2-34 apply to liquids that are mostly water. For lagoons that contain organic fluids, however, the equations may need to be corrected. For liquids with a density or viscosity that differs from water, correct K_s for this different viscosity and density by calculating the term K_c, using the following:

$$K_c = K_w * D_c/D_w * u_w/u_c \qquad (2\text{-}35)$$

where

K_c = corrected K_s term = hydraulic conductivity of contaminant, (length/time).
K_w = hydraulic conductivity of ground water, (length/time).
D = density of liquids: c = contaminant, w = water, (mass/volume).

P_e = effective porosity, (dimensionless fraction).

The above terms should be determined for the site being studied. If this is not possible for all parameters, then literature values can be used for the few parameters that are not available. Literature values for saturated hydraulic conductivity are presented in Table 3-8 (Rawls et al. 1982) and Table 3-9 (Freeze and Cherry 1979).

The hydraulic gradient (the change in the elevation of the water table over distance from the site) should also be taken from field data developed during site investigation. Water levels in existing nearby wells can also provide an indication of hydraulic gradient. Table 3-10 provides values for saturated moisture content, which is roughly equal to the effective porosity, or P_e, for several soil types.

It must be emphasized that site-specific data are highly preferable to regional data, or data obtained from any of the above-referenced tables. If site-specific information on effective porosity is available, it should be used; however, literature values for soils with the same hydraulic conductivity provide sufficient accuracy. Effective porosity (P_e) can be approximated by the difference between the moisture content at saturation and at the wilting point (-15 bar)*. The equation is as follows (Rawls 1986):

$$P_e = \theta_s - \theta(-15) \qquad (3\text{-}11)$$

where

P_e = effective porosity, (fraction, dimensionless).

θ_s = water content when the pores are fully saturated, (fraction, dimensionless).

$\theta(-15)$ = wilting point moisture content, (fraction, dimensionless).

This estimation procedure addresses the fraction of the pore spaces that is contributing to flow, but does not address the effect of electro-osmotic counterflow and the development of electrokinetic streaming potentials. For clays, this can be a significant difference. Literature values listed in Table 3-10 should be used for clay solids (these values incorporate the effects of the clays ionic double layer) (Rawls et al. 1982); either technique can be used for sand or loam soil.

The above method for predicting the average velocity of ground water is the most widely accepted approximation; however, it is only an approximation

and further refinement of this approach would improve accuracy. Corrections for the path length difference between the straight line distance versus the tortuous path through which ground water flows can improve the precision (Freeze and Cherry 1979), although the literature does not provide a consistent correction factor to apply. To provide a feel for the magnitude of this correction, the analyst can review Das (1983) which suggests a correction of 1.41. This value can be used to correct the velocity or the distance (not both) by dividing the number by 1.4. However, the analyst must interpret the results obtained through such correction with care, as the degree to which the factor cited in Das applies to any given site is uncertain.

3.5.2.2 Calculating the Velocity of Infiltrating Rainwater

This section discusses the calculation of the velocity of percolating rainwater flowing through the vadose zone. Darcy's law can be used to calculate the unsaturated flow velocity; however, the hydraulic conductivity must be corrected to reflect the effect of partially-filled pore spaces when the hydraulic loading is below that necessary to support saturated flow.

Interstitial pore water velocity for unsaturated transport through the vadose zone can be calculated as follows (Enfield et al. 1982):

$$v_{pw} = q/\Theta \qquad (3\text{-}12)$$

where

v_{pw} = interstitial ground water (pore water) velocity, (length per unit time).

q = average percolation or recharge rate, (depth per unit time).

Θ = volumetric moisture content of the unsaturated zone, (decimal fraction, representing volume of water per volume of soil).

This equation applies to steady-state conditions, or those that can be assumed to be steady. For unsteady hydraulic loading, the "q" and "Θ" will vary with time and depth. Additionally, the distribution of "q" and "Θ" will vary as the moisture migrates down. This makes determination of the average transport velocity burdensome. For situations where steady-state conditions cannot be assumed, the analyst should use a computer model; for example, SESOIL (one of EPA's GEMS computer system) calculates the time of travel for seasonally varying rainfall rates.

The volumetric water content (Θ) in the unsaturated zone can be estimated using the following equation (Clapp and Hornberger 1978):

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*Wilting point is determined by drawing a suction of -15 bar to draw water out of the soil in a manner similar to the suction of a plant root. Bar is a measure of pressure (dynes/cm^2).

Table 3-8. Representative Values of Saturated Hydraulic Conductivity

Soil texture	Number of soils[a]	Hydraulic conductivity (K_s; cm/sec)[b]
Sand	762	5.8×10^{-3}
Loamy sand	338	1.7×10^{-3}
Sandy loam	666	7.2×10^{-4}
Loam	383	3.7×10^{-4}
Silt loam	1,206	1.9×10^{-4}
Sandy clay loam	498	1.2×10^{-4}
Silt clay loam	366	4.2×10^{-5}
Clay loam	689	6.4×10^{-5}
Sandy clay	45	3.3×10^{-5}
Silt clay	127	2.5×10^{-5}
Clay	291	1.7×10^{-5}

[a]Number of individual soil samples included in data compiled by Rawls et al. 1982.
[b]Predicted values based on compiled soil properties.
Source: Adapted from Rawls et al. 1982.

Table 3-9. Saturated Hydraulic Conductivity Ranges for Selected Rock and Soil Types

Saturated Hydraulic Conductivity (cm/sec)

Soils

Unweathered marine clay	5×10^{-11}	--	10^{-7}
Glacial till	10^{-10}	--	10^{-4}
Silt, loess	10^{-7}	--	10^{-3}
Silty sand	10^{-5}	--	10^{-1}
Clean sand	10^{-4}	--	1
Gravel	10^{-1}	--	10^2

Rocks

Unfractured metamorphic and igneous rock	10^{-2}	--	10^{-8}
Shale	5×10^{-12}	--	10^{-7}
Sandstone	10^{-8}	--	5×10^{-4}
Limestone and dolomite	5×10^{-8}	--	5×10^{-4}
Fractured igneous and metamorphic rock	10^{-6}	--	10^{-2}
Permeable basalt	10^{-5}	--	1
Karst limestone	10^{-4}	--	1

Source: Adapted from Freeze and Cherry 1979.

Table 3-10. Representative Values for Saturated Moisture Contents and Field Capacities of Various Soil Types

	Number of soils	Saturated moisture content (θ_s)[a]		Field capacity (cm3/cm3)[b]	
		Mean	± 1 Standard deviation	Mean	± 1 Standard deviation
Sand	762	0.437	0.347 - 0.500	0.091	0.018 - 0.164
Loamy sand	338	0.437	0.368 - 0.506	0.125	0.060 - 0.190
Sandy loam	666	0.453	0.351 - 0.555	0.207	0.126 - 0.288
Loam	383	0.463	0.375 - 0.551	0.270	0.195 - 0.345
Silt loam	1,206	0.501	0.420 - 0.582	0.330	0.258 - 0.402
Sandy clay loam	498	0.398	0.332 - 0.464	0.255	0.186 - 0.324
Clay loam	366	0.464	0.409 - 0.519	0.318	0.250 - 0.386
Silty clay loam	689	0.471	0.418 - 0.524	0.366	0.304 - 0.428
Sandy clay	45	0.430	0.370 - 0.490	0.339	0.245 - 0.433
Silty clay	127	0.479	0.425 - 0.533	0.387	0.332 - 0.442
Clay	291	0.475	0.427 - 0.523	0.396	0.326 - 0.466

[a]From total soil porosity measurements compiled by Rawls et al. (1982) from numerous sources.
[b]Water retained at -0.33 bar tension; values predicted based on compiled soil property measurements.

Source: Rawls et al. 1982.

$$\Theta = (\Theta_s) * (q/K_s)^{1/(2b+3)} \qquad (3\text{-}13)$$

where

Θ == volumetric water content in the unsaturated zone, (volume/volume or unitless).

Θ_s == volumetric water content of soil under saturated conditions, (volume/volume or unitless).

q == percolation rate (assumed to be equal to the unsaturated hydraulic conductivity term in original Clapp and Hornberger equation), (depth per unit time).

K_s == saturated hydraulic conductivity, (depth per unit time).

b == soil-specific exponential parameter, (unitless).

Representative values of "b" and the term "$1/(2b+3)$" are listed in Table 3-11.

Table 3-11. Representative Values of Hydraulic Parameters (Standard Deviation in Parentheses)

Soil texture	No. of soils[a]	b[b]		$\dfrac{1}{2b+3}$	Θ_s[c]	
Sand	13	4.05	(l.78)	0.090	0.395	(0.056)
Loamy sand	30	4.38	(1.47)	0.085	0.410	(0.068)
Sandy loam	204	4.90	(1.75)	0.080	0.435	(0.086)
Silt loam	384	5.30	(1.87)	0.074	0.485	(0.059)
Loam	125	5.39	(1.87))	0.073	0.451	(0.078)
Sandy clay loam	80	7.12	(2.43)	0.058	0.420	(0.059)
Silt clay loam	147	7.75	(2.77)	0.054	0.477	(0.057)
Clay loam	262	8.52	(3.44)	0.050	0.476	(0.053)
Sandy clay	19	10.40	(1.64)	0.042	0.426	(0.057)
Silt clay	441	10.40	(4.45)	0.042	0.492	(0.064)
Clay	140	11.40	(3.70)	0.039	0.482	(0.050)

[a]Number of individual soil samples included in data compiled by Clapp and Hornberger (1978).
[b]Empirical parameter relating soil matric potential and moisture content; shown to be strongly dependent on soil texture.
[c]Volumetric soil moisture content (volume of water per volume of soil).
Source: Adapted from Clapp and Hornberger 1978.

The saturated volumetric water content (Θ_s), saturated hydraulic conductivity (K_s), and the exponential function (b) are all related to soil properties. The most reliable values for these parameters are empirical values (if available) measured during site investigation. Where empirical values are unavailable, values in Tables 3-10 through 3-11 provide guides for the rough estimation of Θ_s, K_s, and the term $1/2b+3$. Representative values from two different sources are presented for K_s (Tables 3-8 and 3-9) and Θ_s (Tables 3-10 and

3-11), in order to demonstrate the variability in estimates for these values.

Note that the value Θ cannot exceed Θ_s, the saturated soil moisture content. When Θ calculated by Equation 3-13 equals or exceeds Θ_s, it must be assumed that saturated conditions exist. In such cases, use Equations 3-9 and 3-10.

Similarly, the minimum value for Θ that is applicable to Equation 3-13 is the field capacity of the soil. This value represents the volumetric moisture content remaining in the soil following complete gravity drainage and is the moisture content below which downward flow of water due to gravity through unsaturated soil ceases. Field capacity is a function of soil type; the most reliable values are those measured empirically. Where measured values are not available, default values can be taken from Table 3-10. Wherever Equation 3-13 results in a value for Θ that is less than the specific retention of the soil, it should be assumed that no downward movement of moisture (and dissolved contaminant) occurred for the associated time increment, and that V_{pw} is equal to zero.

Note that the percolation rate (q) cannot exceed the saturated hydraulic conductivity (K_s) for the site soil. Whenever $q \geq K_s$ (and therefore Θ as calculated by Equation 3-13 $\geq \Theta_s$) for the duration of the study period, it must be assumed that saturated conditions exist and that saturated flow prevails. Equations 3-9 and 3-10 in the preceding subsection provide a means of estimating saturated flow velocities.

The following equation provides an estimate of the term q (Enfield et al. 1982):

$$q = HL + P_r - ET - Q_r \qquad (3\text{-}14)$$

where

HL = hydraulic loading from manmade sources, (depth per unit time)
P_r = precipitation, (depth per unit time)
ET = evapotranspiration, (depth per unit time)
Q_r = runoff, (depth per unit time).

Records of estimated percolation rates for the site locality during the time period in question (or annual average percolation rate estimates) are often available from local climate or soil authorities, including regional U.S. Geological Survey (USGS) and U.S. Soil Conservation Service offices.

An estimation procedure can be used to evaluate percolation rates (q) at sites where the sources listed above cannot provide them directly. This estimation procedure requires data for precipitation, evaporation, and runoff rates. In addition to the above two sources,

Table 1
Water Analytical Results
Pond Release Investigation
Cherry Blossom LLC
ISE Project #02061

Sample ID		A	A	B	B	B
Sample Location	DWC	Wastewater Pond, Area A	Wastewater Pond, Area A	Upper Parking Level Stormwater Retention Pond, Area B	Upper Parking Level Stormwater Retention Pond, Area B	Upper Parking Level Stormwater Retention Pond, Area B
Date Collected		11/22/05	11/23/05	11/22/05	11/22/05	11/23/05
Date Extracted		NA	NA	NA	NA	NA
Date Analyzed		11/22/05	11/29/05	11/22/05	11/22/05	11/29/05
Collection Method		Grab	Grab	Grab	Grab	Grab
Analytical Method No.		NA	20-Nov	NA	NA	20-Nov
Dissolved Oxygen (mg/L)		1.57	NA	0.02	0.01	NA
Temperature (degrees C)		4.2	NA	3.3	3.3	NA
pH		5.33	NA	6.69	6.71	NA
Conductivity (mS/cm)		4.54	NA	0.659	0.634	NA
Chloride (mg/L, PPM)	250	NA	865	NA	NA	105

NOTES:
NA: Not Analyzed
(E) -Criterion is the aesthetic
drinking water value
DWC - Residential & Commercial I Drinking Water Criteria & RBSLs

Table 1
Water Analytical Results
Pond Release Investigation
Cherry Blossom LLC
ISE Project #02061

Sample ID		C	C	D	D	E
Sample Location	DWC	Lower Stormwater Retention Pond (behind Maint. Bldg), Area B	Lower Stormwater Retention Pond (behind Maint. Bldg), Area B	South side Angel, Tobeco Creek	South side Angel, Tobeco Creek	South side Angel, Off-Site Accumulation Area, Area D
Date Collected		11/22/05	11/23/05	11/22/05	11/22/05	11/22/05
Date Extracted		NA	NA	NA	NA	NA
Date Analyzed		11/22/05	11/29/05	11/22/05	11/22/05	11/22/05
Collection Method		Grab	Grab	Grab	Grab	Grab
Analytical Method No.		NA	20-Nov	NA	NA	NA
Dissolved Oxygen (mg/L)		7.34	NA	9.97	10	4.46
Temperature (degrees C)		2.7	NA	1.3	1.4	1
pH		6.83	NA	7.45	7.45	7.17
Conductivity (mS/cm)		1.17	NA	0.36	0.36	0.357
Chloride (mg/L, PPM)	250	NA	200	NA	NA	NA

NOTES:
NA: Not Analyzed
(E) -Criterion is the aesthetic
drinking water value
DWC - Residential & Commercial I Drinking Water Cri

Table 1
Water Analytical Results
Pond Release Investigation
Cherry Blossom LLC
ISE Project #02061

Sample ID		E	E	F	F	TMW-1	TMW-2
Sample Location	DWC	South side Angel, Off-Site Accumulation Area, Area D	South side Angel, Off-Site Accumulation Area, Area D	Surface Water Sample, Area D, WS-F (N)	Surface Water Sample, Area D, WS-F (S)	South, Area D	North, Area D
Date Collected		11/22/05	11/22/05	12/02/05	12/02/05	12/05/05	12/05/05
Date Extracted		NA	NA	NA	NA	NA	NA
Date Analyzed		11/22/05	11/22/05	12/06/05	12/06/05	12/07/05	12/07/05
Collection Method		Grab	Grab	Grab	Grab	Grb	Grab
Analytical Method No.		NA	NA	20-Nov	325.2	325.2	325.2
Dissolved Oxygen (mg/L)		4.62	4.63	NA	NA	NA	NA
Temperature (degrees C)		0.8	0.6	NA	NA	NA	NA
pH		7.09	7.07	NA	NA	NA	NA
Conductivity (mS/cm)		0.409	0.42	NA	NA	NA	NA
Chloride (mg/L, PPM)	250	NA	NA	28	36	184	52

NOTES:
NA: Not Analyzed
(E) -Criterion is the aesthetic
drinking water value
DWC - Residential & Commercial I Drinking Water Cri

Table 2
Soil Analytical Results
Pond Release Investigation
Cherry Blossom LLC
ISE Project #02061

Sample ID		SB-101	SB-102	SB-103	SB-104	SB-105
Sample Location	Direct Contact Criteria & RBSLs	0-1'	0-1'	0-1'	0-1'	0-1'
Date Collected		11/23/05	11/23/05	11/23/05	11/23/05	11/23/05
Date Extracted		NA	NA	NA	NA	NA
Date Analyzed		11/29/05	12/06/05	11/29/05	12/07/05	12/07/05
Collection Method		Grab	Grab	Grab	Grab	Grab
Analytical Method No.		EPA 9251	EPA 9251	EPA 9251	EPA 9251	EPA 9251
Chloride (mg/kg, PPM)	500 (F)	1,500	30	464	328	228
Solids, Total (%)			86.9		86.3	82.5
Soil Moisture (%)		29.2	13.1	8.6	13.8	17.5

NOTES:
NA: Not Analyzed
(F): Criterion is based on adverse
impacts to plant life and
phytotoxicity

Table 2
Soil Analytical Results
Pond Release Investigation
Cherry Blossom LLC
ISE Project #02061

Sample ID		SB-106	SB-107	SB-108	SB-109	SB-110
Sample Location	Direct Contact Criteria & RBSLs	0-1'	0-1'	0-1'	0-1'	0-1'
Date Collected		11/23/05	11/23/05	11/23/05	11/23/05	11/23/05
Date Extracted		NA	NA	NA	NA	NA
Date Analyzed		11/29/05	12/06/05	11/29/05	11/29/05	11/29/05
Collection Method		Grab	Grab	Grab	Grab	Grab
Analytical Method No.		EPA 9251	EPA 9251	EPA 9251	EPA 9251	EPA 9251
Chloride (mg/kg, PPM)	500 (F)	275	83	610	173	2,020
Solids, Total (%)			65.1			
Soil Moisture (%)		5.1	34.9	12.0		7.6

NOTES:
NA: Not Analyzed
(F): Criterion is based on adverse impacts to plant life and phytotoxicity

Table 2
Soil Analytical Results
Pond Release Investigation
Cherry Blossom LLC
ISE Project #02061

Sample ID		SB-111	SB-111	SB-112	SB-114	SB-115	SB-116
Sample Location	Direct Contact Criteria & RBSLs	0-1'	4-5'	0-1.0'	0-0.75'	0-0.5'	0-0.75'
Date Collected		11/23/05	11/23/05	11/23/05	11/23/05	11/23/05	11/23/05
Date Extracted		NA	NA	NA	NA	NA	NA
Date Analyzed		11/29/05	11/29/05	11/29/05	12/06/05	12/06/05	12/06/05
Collection Method		Grab	Grab	Grab	Grab	Grab	Grab
Analytical Method No.		EPA 9251	EPA 9251	EPA 9251	EPA 9251	EPA 9251	EPA 9251
Chloride (mg/kg, PPM)	500 (F)	314	19	214	168	3,240	557
Solids, Total (%)					80.8	90.3	93.2
Soil Moisture (%)		4.1	10.5	7.5	19.2	9.7	6.8

NOTES:
NA: Not Analyzed
(F): Criterion is based on adverse
impacts to plant life and
phytotoxicity

Table 2
Soil Analytical Results
Pond Release Investigation
Cherry Blossom LLC
ISE Project #02061

Sample ID		SB-117	SB-118	SB-118	SB-119	SB-122	SB-123
Sample Location	Direct Contact Criteria & RBSLs	0-0.75'	0-0.75'	1.5-2'	0-0.75'	0-1'	0-1'
Date Collected		11/23/05	11/23/05	12/02/05	12/02/05	12/02/05	12/02/05
Date Extracted		NA	NA	NA	NA	NA	NA
Date Analyzed		12/06/05	12/06/05	12/06/05	12/06/05	12/06/05	12/06/05
Collection Method		Grab	Grab	Grab	Grab	Grab	Grab
Analytical Method No.		EPA 9251	EPA 9251	EPA 9251	EPA 9251	EPA 9251	EPA 9251
Chloride (mg/kg, PPM)	500 (F)	1,450	743	1,600	22	937	1,130
Solids, Total (%)		91.1	90.5	86.9	90.6	72.9	39.5
Soil Moisture (%)		8.9	9.5	13.1	9.4	27.1	60.5

NOTES:
NA: Not Analyzed
(F): Criterion is based on adverse
impacts to plant life and
phytotoxicity

Table 2
Soil Analytical Results
Pond Release Investigation
Cherry Blossom LLC
ISE Project #02061

Sample ID		SB-124	SB-125	SB-126	SB-127	SB-128	SB-129
Sample Location	Direct Contact Criteria & RBSLs	0-1'	0-1'	0-1'	0.5'	0.5'	0.5'
Date Collected		12/05/05	12/05/05	12/05/05	12/05/05	12/05/05	12/05/05
Date Extracted		NA	NA	NA	NA	NA	NA
Date Analyzed		12/07/05	12/07/05	12/07/05	12/07/05	12/07/05	12/07/05
Collection Method		Grab	Grab	Grab	Grab	Grab	Grab
Analytical Method No.		EPA 9251	EPA 9251	EPA 9251	EPA 9251	EPA 9251	EPA 9251
Chloride (mg/kg, PPM)	500 (F)	336	1,250	46	115	40	107
Solids, Total (%)		70.0	64.7	58.8	77.1	87.6	85.1
Soil Moisture (%)		30.0	35.3	41.2	22.9	12.4	14.9

NOTES:
NA: Not Analyzed
(F): Criterion is based on adverse impacts to plant life and phytotoxicity

Table 2
Soil Analytical Results
Pond Release Investigation
Cherry Blossom LLC
ISE Project #02061

Sample ID		SB-130	TMW-1	TMW-2
Sample Location	Direct Contact Criteria & RBSLs	3'	1.5'	2'
Date Collected		12/05/05	11/23/05	11/23/05
Date Extracted		NA	NA	NA
Date Analyzed		12/07/05	12/07/05	12/07/05
Collection Method		Grab	Grab	Grab
Analytical Method No.		EPA 9251	EPA 9251	EPA 9251
Chloride (mg/kg, PPM)	500 (F)	584	2,140	43
Solids, Total (%)		90.6	72.6	87.0
Soil Moisture (%)		9.4	27.4	13.0

NOTES:
NA: Not Analyzed
(F): Criterion is based on adverse
impacts to plant life and
phytotoxicity

Table 3
Vertical Pore Velocity Calculations
Pooled Areas, November Release
Cherry Blossom LLC
ISE Project #02061

Area	Vertical Pore Velocity, Vpw, inches/Year	Percolation Rate (q) in/year(Kalkaska data,)	Percolation Rate (q) (cm/sec)	Saturated Hydraulic Conductivity,Ks (cm/sec, EPA document)	Volumetric water content in unsaturated zone, θ (unitless)	θ_s, volumetric water content of soil under saturated conditions (unitless, EPA document)	1/(2b+3) value, b is soil specific exponential parameter, unitless (EPA Doc)
A, B, C	23.8	15.4	0.105	0.00072	0.648	0.435	0.080
D	19.9	15.4	0.105	0.00019	0.774	0.485	0.074

Equation 1: Percolation rate   q (depth per unit time) $= HL + P_r - ET - Q_r$

where HL = Hydraulic loading from manmade sources, (depth per unit time)

       P_r = Precipitation, (depth per unit time)

       ET = Evapotranspiration, (depth per unit time)

       Q_r = Runoff, (depth per unit time)

Equation 2: Interstitial pore velocity: v_{pw} (depth per unit time) $= q/\Theta$

where v_{pw} = Interstitial ground water (pore water) velocity, (lenth per unit time)

       q = average percolation or recharge rates (see above)

       Θ = volumetric moisture content of the unsaturated zone, (decimal fraction representing volume of water per volume of soil)

Fate transport equations

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